UNITED STATES PATENT APPLICATION

For

THREE-DIMENSIONAL ULTRASONIC MAMMOGRAPHY SCANNING

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THREE-DIMENSIONAL ULTRASONIC MAMMOGRAPHY SCANNING

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application is related to and claims the benefit of U.S. Provisional Application Serial No. 60/392,343, filed June 28, 2002, entitled "Scanning Devices for Three-Dimensional Ultrasound Mammography," the content of which is incorporated herein by reference as though fully set forth.

BACKGROUND OF INVENTION

[0002] *Field of Invention*

[0003] This invention relates to tomography and, more particularly, to three-dimensional, ultrasound tomographic mammography.

[0004] *Description of Related Art*

[0005] One approach to ultrasound breast tomography has been to have the female subject lie in the prone position in a special bed and suspend one of her breasts into a container filled with acoustical coupling fluid. Ultrasonic transducers are arranged to rotate about the suspended breast in the fluid-filled container. Transmission or reflection projections are measured and used to reconstruct tomographic images.

[0006] The rotation of the ultrasonic transducers around the breast can cause currents in the fluid and, in turn, movement of the breast during the scanning process. This can distort the tomographic images.

[0007] One effort at dealing with this problem is set forth in a U.S. Patent 4,105,018, issued on August 8, 1978. Figure 3 of this patent illustrates a stationary pedestal on which the lowest portion of the breast is rested. Unfortunately, the use of such a pedestal can complicate the mechanics and process by requiring a height adjustment mechanism and associated process to accommodate breasts of different sizes. Also, it may not prevent the turbulence in the fluid from causing upper portions of the breast to vibrate during the scanning process.

[0008] Another approach is to surround the breast with a stationary foil, as shown in Fig. 7 of U.S. Patent 4,485,819, issued on December 4, 1984. Unfortunately, this

approach may interfere with the ultrasound signals and can restrict the ability of the system to scan portions of the breast close to the chest.

SUMMARY OF THE INVENTION

[0009] A breast tomography scanner may include a stationary chamber configured to hold fluid; a movable chamber within the stationary chamber configured to hold fluid, to move relative to the stationary chamber, and to receive a breast; and breast scanning apparatus configured to scan the breast received by the movable chamber.

[0010] The breast scanning apparatus may include an ultrasonic transmitter and an ultrasonic receiver coupled to the movable chamber and positioned to receive the breast between them.

[0011] The movable chamber may have an upper rim and the ultrasonic transmitter and the ultrasonic receiver may be located at the upper rim.

[0012] The breast tomography scanner may also include a housing affixed to the upper rim in which the ultrasonic transmitter and ultrasonic receiver are contained. The housing may include a recessed cavity surrounding the ultrasonic transmitter and the ultrasonic receiver.

[0013] The movable chamber may be configured to rotate about a vertical axis within the stationary chamber.

[0014] The movable chamber may be configured to move vertically.

[0015] The movable chamber may have one or more fluid communication channels other than at its top configured to allow fluid to flow between the movable chamber and the stationary chamber.

[0016] The movable chamber may have a bottom **113** and the fluid communication channel(s) may be in the bottom **113**. The movable chamber may have a cylindrical wall and the fluid communication channel(s) may be adjacent the wall.

[0017] The movable chamber may have a cylindrical wall and the fluid communication channel(s) may be in the cylindrical wall. The movable chamber may have a bottom and the fluid communication channel(s) may be adjacent the bottom.

[0018] The breast tomography scanner may include a shaft extending though the stationary chamber and affixed to the movable chamber.

[0019] The breast tomography scanner may include a leak-resistant bearing between the shaft and the stationary chamber.

[0020] The breast tomography scanner may include a collection chamber positioned beneath the leak-resistant bearing and configured to collect fluid that leaks past the leak-resistant bearing. A suction device may be connected to the collection chamber to remove fluid collected in the collection chamber.

[0021] The breast tomography scanner may include a leak collection tray positioned beneath the collection chamber to collect fluid that leaks past the collection chamber. An alarm may be in communication with the collection tray and configured to sound in the event that fluid leaks onto the leak collection tray. A power shut off circuit may be in communication with the collection tray and configured to remove power from the breast tomography scanner in the event that fluid leaks onto the leak collection tray.

[0022] The shaft may have an interior, the breast scanning apparatus may include an ultrasonic transducer coupled to the movable chamber, and electrical wires may be attached to the ultrasonic transducer that pass though the interior of the shaft. The electrical wires may be protected from exposure to fluid that is placed in the movable chamber. The electrical wires may be attached to a slip ring assembly mounted to the shaft.

[0023] The movable chamber may be configured to hold a fluid up to a first level and the stationary chamber may be configured to hold fluid up to a level that is higher than the first level.

[0024] The breast tomography scanner may include a chamber filling pump configured to cause fluid to fill the movable chamber and the stationary chamber and a processor configured to control the operation of the chamber filling pump such that the chamber filling pump causes the fluid level in both the movable chamber and the stationary chamber to exceed the first level.

[0025] The stationary chamber and the movable chamber may be configured such that the level of fluid within both of them equalizes.

[0026] The breast tomography scanner may include a table top having a top surface and a bottom surface positioned above the movable chamber and an opening in the table top extending from the top surface to the bottom surface, positioned above the movable chamber, and configured to receive a breast.

[0027] The breast tomography scanner may include a drain positioned under the top surface of the table and configured to prevent fluid from flowing from the stationary chamber or movable chamber to the top surface of the table. The drain may be positioned between the top and bottom surface of the table top and be in fluid communication with the opening.

[0028] The top surface, but not the bottom surface, may be tapered downwardly in the area of the opening.

[0029] The breast tomography scanner may include a drain at the bottom of the stationary chamber to drain fluid from the chamber and a slanted surface at the bottom of the stationary chamber configured to direct fluid towards the drain.

[0030] These as well as still further features, benefits and objects will now become clear upon an examination of the following detailed description of illustrative embodiments and the attached drawings.

BRIEF DESCRIPTION OF DRAWINGS

[0031] FIG. 1 illustrates various components that may be used in a breast tomography scanner.

[0032] FIGS. 2A-D illustrate a housing for transducers that may be used in a breast tomography scanner.

[0033] FIGS. 3A-D illustrate another embodiment of a housing for transducers that may be used in a breast tomography scanner.

[0034] FIGS. 4A-B illustrate a leak collection and detection tray that may be used in a breast tomography scanner.

[0035] FIG. 5 illustrates a scanning pattern containing of a stacked set of tomographic images.

[0036] FIG. 6 illustrates additional components that may be used in a breast tomography scanner.

[0037] FIG. 7 illustrates electronics that may be used in a breast tomography scanner.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

[0038] FIG. 1 illustrates various components that may be used in a breast tomography scanner.

[0039] As shown in FIG. 1, a female subject **101** may lie in the prone position on a top surface **102** of a table **103**. A breast **104** of the female subject **101** may be dangled through an opening **105** in the table **103**.

[0040] The opening **105** may be circular in shape or may have a different shape. The opening **105** may include an incline **133** that tapers from the top surface **102** to at or near a bottom surface **141** of the table **103**. Although shown as a straight taper, it is to be understood that other contours could be used instead for the incline **133**.

[0041] The incline **133** may increase the comfort of the female subject **101**, increase the hanging depth of portions of the breast **104** that are closest to the chest, thereby allowing more of these portions to be scanned, and also reduce the tendency for fluid to overflow to the top surface **102** of table **103**.

[0042] The incline **133** may not extend below the level of the bottom surface **141** of the table **103**. This may increase the height to which the ultrasonic transducers (discussed below) can rise, thus again maximizing the ability of the system to scan portions of the breast **104** that are closest to the chest. Other configurations and locations of the incline **133** could be used instead.

[0043] Although the opening **105** is illustrated as being tapered with an incline **133** in FIG. 1, it is to be understood that the edge could be squared or otherwise configured.

[0044] Beneath the table **103** and surrounding the opening **105** may be a stationary chamber **107** filled with a fluid **109**. The stationary chamber **107** may be cylindrical, may be of another shape that has axial symmetry, or may be of another shape. It may also be integral, affixed to, detachable from, or detached from the table **103**.

[0045] Within the stationary chamber **107** may be a movable chamber **108** that can be moved with respect to the stationary chamber **107**. The movable chamber **108** may be cylindrical, may be of another shape that has axial symmetry, or may be of another shape. The movable chamber **108** may have its upper opening positioned beneath the opening **105** of the table **103**. The movable chamber **108** may be filled with a fluid **152**.

[0046] The movable chamber **108** may include an upper rim **151** at or about which are positioned one or more ultrasonic transducers, such as an ultrasonic transmitter **110** and an ultrasonic receiver **111**.

[0047] The ultrasonic transducer or transducers may operate in the transmission or reflection mode. It may be a single transducer or there may be multiple transducers, such as a linear array of piezoelectric elements or a two-dimensional array of piezoelectric elements.

[0048] The ultrasonic transducers may be integral with the movable chamber **108**. They may instead be contained within a separate housing that is attached at the upper rim **151** of the movable chamber **108**.

[0049] FIGS. 2A-D illustrate a housing **201** that may be used in a breast tomography scanner. FIG. 2A is a perspective view of the housing **201**, FIG. 2B is a side view, FIG. 2C is a top view, and FIG. 2D shows the housing **201** affixed to the top rim **151** of the movable chamber **108**. A waterproof gasket or sealant may be placed between the housing **201** and the top rim **151**.

[0050] As shown in FIGS. 2A-D, the ultrasonic transmitter **110** and the ultrasonic receiver **111** may be mounted within the housing **201**. The housing **201** may be doughnut-shaped and have an exterior profile that substantially aligns with the exterior profile of the movable chamber **108**. It may have an interior opening **250** that

substantially coincides with the size of the opening for the breast in the movable chamber **108**, or at least the diameter of the largest breast intended to be scanned.

[0051] The transmitter **110** and receiver **111** may be positioned such that the two are directly facing one another and such that the acoustic energy generated by the ultrasonic transmitter **110** is directed to the ultrasonic receiver **111** across the opening **250**, thereby causing the breast that is inserted within this opening to be scanned during operation.

[0052] The ultrasonic transmitter **110** and the ultrasonic receiver **111** may be sized and positioned such that their apertures **210** and **211** do not protrude into the area of the opening **250**. The housing **201** may include covering portions **260** on the top and bottom portions of the housing **201** to create in conjunction with the ultrasonic transmitter **110**, the ultrasonic receiver **111**, and semi-cylindrical adjoining walls **261** and **263** a recessed cavity. This cavity may be configured to create stagnant liquid layers in the recessed pockets, reducing turbulence in the fluid as the movable chamber **108** is rotated as described in more detail below.

[0053] FIGS. 3A-D illustrate another embodiment of a housing **301** for transducers that may be used in a breast tomography scanner. This configuration is similar to the one shown in FIGS. 2A-D, except that there are no protective covering portions on the top and bottom portions of the housing **301** and thus no associated recessed cavity. Instead, the apertures **210** of the ultrasonic transmitter **110** and **211** of the ultrasonic receiver **111** may protrude into the opening **350**. This embodiment allows the opening **350** to be wider at most of its points.

[0054] Referring again to FIG. 1, a shaft **117** may be coupled to the movable chamber **108**, such as at the center of the bottom **113** of the movable chamber **108**. The shaft **117** may include a hollow portion in which electrical wires **115** and **116** may reside. Electrical wires **115** and **116** may be connected to the ultrasonic transmitter **110** and the ultrasonic receiver **111**, respectively, through conduits in the movable chamber **108**. Maintaining the wires within the conduits of the movable chamber **108** and shaft **117** may insure that they do not come in contact with the fluid **109** or **152**.

[0055] Through the application of appropriate forces to the shaft **117** (discussed in more detail below in connection with FIG. 6), the movable chamber **108** may be caused to rotate about an axis **119**, as indicated by rotating arrows **165**. The movable chamber **108** may also be caused to move vertically, parallel to the axis **119**, as reflected by movement arrows **149**.

[0056] FIG. 5 illustrates a scanning pattern containing of a stacked set of tomographic images **503**. In one mode of operation, the shaft **117** is raised until the ultrasonic transmitter **110** and the ultrasonic receiver **111** are raised as close to the chest of the female subject **101** as possible, without contacting the bottom surface **141** of the table **103.** The shaft may then be operated to cause the movable chamber **108** to rotate at this vertical position. During this rotation, the ultrasonic transmitter **110** may direct ultrasonic beams **112** through the dangled breast to the ultrasonic receiver **111**. The beams **112** are received during the rotation after being attenuated by the tissue in the breast by the ultrasonic receiver **111**. The received projection may then be processed to create a first two-dimensional tomographic image **501** in accordance with well-known processing techniques.

[0057] Following the acquisition of the first two-dimensional tomographic image **501**, the shaft **117** may be incrementally lowered, causing the movable chamber **108** to be lowered. The shaft **117** may then be again rotated at this second vertical position, again causing the movable chamber **108** to be rotated. A second, two-dimensional tomographic image **502** may then be acquired. This process may then be repeated until the ultrasonic transducers **110** and **111** are lowered past the lowermost portion of the breast **104** that is of interest. The series **503** of tomographic images that are created may then be processed in accordance with well-known processing techniques to construct a three-dimensional image of the breast **104**.

[0058] Other movement sequences may also or instead be used. For example, the shaft **107** may be rotated and moved vertically at the same time, causing the ultrasonic transducers to sweep a helical path.

[0059] Fluid may be pumped into the stationary chamber **107** and, in turn, into the movable chamber **108**, by a filling pump **137** communicating through a tube **138** with a

controllable valve **136** and through another tube **139** to a fluid inlet **135** at the base of the stationary chamber **107**.

[0060] The amount of fluid that is pumped into the stationary chamber **107** and the movable chamber **108** may vary. In one embodiment, the movable chamber **108** may be configured to hold fluid up to a first level, while the stationary chamber **107** may be configured to hold fluid up to a level that is higher than the first level. In this embodiment, fluid pumped into the stationary chamber **107** may rise above the level of the movable chamber **108** and flow over the upper rim **151** into the movable chamber **108**. This may reduce turbulence that might otherwise be caused as the movable chamber **108** is lowered vertically by the shaft **117** during the scanning process.

[0061] Fluid-communication channels **134**, such as holes, may also be placed in the bottom **113** of the movable chamber **108** to allow fluid to flow between the movable chamber **108** and the stationary chamber **107**. These channels may also be placed in the side-walls of the movable chamber **108**.

[0062] Communication channels **134** may help to reduce turbulence in the fluid during the scanning process. The communication channels **134** may be positioned as close to the outer corners of the bottom **113** of the movable chamber **108**, such as next to the outer wall when placed in the bottom **113** or next to the bottom **113** when placed in the outer wall. Communication channels **134** may also make it easier to drain the movable chamber **108** (as described in more detail below) and may minimize air bubbles that otherwise might occur during filling.

[0063] A drain **121** may also be provided at the bottom **120** of the stationary chamber **107** to drain the fluids **109** and **152**. The drain **121** may be connected by a tube **122** to a controllable valve **123** which, in turn, may be connected by a tube **162** to a suction pump **124**. Although the drained fluid could be reused, it could instead be disposed of for sanitary reasons. To maximize the amount of fluid that is drained, the bottom surface **145** of the stationary chamber **107** may be slanted to direct the fluid toward the drain **121**.

[0064] Efforts may be made to minimize leakage of fluid between the shaft **117** and the stationary chamber **107**. One such effort is to include a leak-resistant bearing **118** between the two.

[0065] Fluid may still leak between the shaft **117** and the stationary chamber **107**. In anticipation of this possibility, a fluid collection chamber **126** may be provided beneath the leak-resistant bearing **118**, either integral to the stationary chamber **107** as shown, or separated from it. To remove any fluid that collects in the fluid-collection chamber **126**, a fluid outlet **128** may be provided that is connected by a tube **163** to a suction pump **130** which, in turn, may be connected by a tube **164** to reservoir **131**.

[0066] If desired, appropriate fluid sensors can be included in the fluid collection chamber **126** to cause the suction pump **130** to be activated only when fluid is detected in the fluid-collection chamber **126**. The pump **130** may instead run continuously to insure that any fluid that may leak into the fluid-collection chamber is removed immediately.

[0067] Appropriate sensors may also be provided in the reservoir **131** to signal when there is leakage and/or when the reservoir must be emptied. Tube **164** may instead be connected to a drain.

[0068] To avoid a vacuum forming in the fluid-collection chamber **126** while collected fluid is being expelled by the suction pump **130**, an air inlet tube **129** may be connected to an air inlet **127** at one end and exposed at the other end to air.

[0069] As an additional or different type of leak protection system, a leak collection and detection tray **132** may also be provided.

[0070] FIGS. 4A and 4B illustrate a leak collection and detection tray **132** that may be used in a breast tomography scanner. As shown in FIGS. 4A and 4B, the leak collection and detection tray **132** may include an opening **401** through which the shaft **117** passes. It may also include a water sensor, such as an interlaced mesh of bare wires **404** and **405**. These wires may be insulated from the tray **132**. When the tray is wet by leaking fluid, the resistance between the intermesh of bare wires **404** and **405**

may drop, and this drop in resistance may be detected over a pair of detection wires **406**.

[0071] Referring again to Fig. 1, protection may be provided to insure that fluid does not flow onto the top **102** of the table **103**. Such protection may include one or more overflow drain holes **145** between the top surface **102** and the bottom surface **141** of the table **103**. The drain holes **145**, in turn, may communicate with a circumferential collection channel **146** that drains into an overflow draining tube **147**.

[0072] The fluid **109** and **152** may be an acoustical coupling fluid and may include a biologically safe surfactant material to reduce its surface tension with the breast **104** and the movable chamber **108**.

[0073] The surfaces within the movable chamber **108**, as well as the surface of the shaft **117**, may be smooth and coated with a hydrophobic paint to reduce the fluid agitation that may be created when these surfaces are moved. The movable chamber **108** may also be made of hydrophobic plastic.

[0074] FIG. 6 illustrates additional components that may be used in a breast tomography scanner.

[0075] As shown in FIG. 6, the scanner may include one or more vertical columns **801** that support the table **103** and the internal components of the scanner.

[0076] The scanner may also include guide rails **603** that support the stationary chamber **107** and act as guides for the vertical translation of a stage **604**.

[0077] A controlled, linear translation motor assembly **605** may be connected to the stage **604** to raise and lower the stage, so as to control its vertical position. Bearings **606** may be included for smooth sliding of the stage **604** on the guide rails **603**.

[0078] The stage **604** may carry a computer-controlled motor assembly **607** that is coupled to the shaft **117**. The stage **604** may also include a slip-ring assembly **608**. The rotating portion of the slip-ring assembly **608** may be connected to the electrical wires **115** and **116** shown in FIG. 1, while the stationary portion of the slip-ring assembly **608** may be connected to corresponding stationary electrical wires for delivering and picking up signals from the wires **115** and **116**, respectively.

[0079] In lieu of the slip-ring assembly **608** or a similar connection system, the motor assembly **607** may be driven so as to merely cause the movable chamber **108** to rotate back and forth, like the agitator in a washing machine. In this embodiment, the slip-ring assembly **608** may be replaced by a loose coil of the cables **115** and **116**. This latter approach might reduce the complexity of the electrical connections and the susceptibility of the system to electrical noise.

[0080] FIG. 7 illustrates electronics that may be used in a breast tomography scanner. A processor **701** may start the imaging session by causing the filling valve **136** to open and the filling pump **137** to begin pumping fluid into the stationary chamber **107**. A pre-determined volume of fluid may be pumped or liquid level sensors (not shown) may be placed near the rim of the breast opening **105** to detect when the chambers are full.

[0081] After the fluid filling process begins, the processor **701** may energize the suction pump **130** to insure that fluid does not leak into the lower portions of the scanner and in the vicinity of the electronics. The processor **701** may cause the suction pump to run throughout the filling and scanning process and until the fluid is later emptied. The processor **701** may instead be connected to a sensor positioned within the fluid collection chamber **126** and only energize the suction pump **130** when the fluid sensor detects the presence of fluid within the fluid collection chamber **126**.

[0082] Once the stationary chamber **107** and movable chamber **108** have been fully filled with fluid, the processor **701** may deliver instructions to a motor controller **703** to cause the linear translation motor assembly **705** and the computer-controlled rotor motor assembly **707** to raise the movable chamber **108** to its highest position.

[0083] The processor **701** may then cause a pulser array **705** to generate excitation pulses that are delivered through the slip-ring assembly **608** to the ultrasonic transmitter **110**. The ultrasonic signals generated by the ultrasonic transmitter **110** may then pass through the breast **104** to the ultrasonic receiver **111**. The received signals may be converted to electrical signals by the ultrasonic receiver **111** and delivered through the slip-ring assembly **608** to an amplifier array **707** and then a pre-processor array **715** to create a projection.

[0084] The processor **701** may then signal the motor controller **703** to cause the movable chamber **108** to incrementally rotate, following which a second projection is created. This processor may repeat this process until the moving chamber **108** has gone through an entire rotation, following which the set of projections obtained during this rotation may be combined using know techniques to create a tomographic image of a slice of the breast **104**.

[0085] The processor **701** may then direct the motor controller to incrementally lower the movable chamber **108**, followed by instructions that would create a tomographic image of a second slice of the breast **104.** This process may repeat until all portions of interest in the breast have been scanned. The tomographic images may then be combined using well known techniques to create a three-dimensional image of the breast.

[0086] The processor **701** may instead issue instructions to the motor controller **703** to cause the ultrasonic transducers to traverse a helix. Other scan patterns may also be used.

[0087] The ultrasonic receiver **111** may have embedded, or included in close proximity, one or more pre-amplifiers to boost the electrical signals prior to their transmission to the slip-ring assembly **708**.

[0088] Although not shown, it is to be understood that the processor **701** may be in communication with the motor controller **703**, the motor **705**, the motor **707**, and/or with movement sensors in the vicinity of the movable chamber **108** so as to provide a means to synchronize the signals that are received by the ultrasonic receiver **111** with the rotational and translational movement of the ultrasonic transducers. The processor **701** may cause the movable chamber **108** to move in increments movements and to cause a measurement of the signal received by the acoustic receiver **111** after each incremental movement, as discussed above, or it may instead and/or in addition cause the movable chamber **108** to continuously rotate and/or vertically translate.

[0089] The end of the scanning process may be signaled by the detection of a dramatic change in the nature of the signal received by the acoustic receiver **111**, by a position-sensing switch near the bottom of the stationary chamber **107**, or in an open-

loop manner by completion of a pre-programmed set of commands that the processor **701** sends to the motor controller **703**.

[0090] Whatever the method, the processor **701** at the end of the scan may direct the draining valve **123** to open and the draining pump **124** to energize. The completion of the draining process could be dictated in an open-loop manner by a timer or in a closed-loop manner by a sensor that senses the absence of fluid in the stationary chamber **107**.

[0091] The sensor on the leak collection and detection tray **132** may be in communication with a driver circuit **709** that detects the presence of fluid on the leak collection and detection tray **132** throughout filling, imaging and draining process. If fluid is detected at any point, a main circuit breaker **711** may be opened, shutting down power to the system, and a battery-operated leakage alarm **713** may be sounded.

[0092] Although certain features, benefits and embodiments have now been described, it is to be understood that this application is not limited to these features, benefits and embodiments, but solely to the subject matter delineated by the following claims and its equivalents.